AP Biology

Unit 3.3 – Cellular Communication

Notes & Practice Quiz

Contents

Section 1 – Types of Cell Communication

1.1 – How do molecules in a cell communicate signals?

Within a cell molecules must communicate with one another about their needs in order to maintain homeostasis. As one molecule comes into contact with another, it transfers some form of energy to the receiving molecule. Sometimes molecules will bind to others and cause the recipient to change shape and thus inhibit or amplify its function. In other instances molecule attachment energizes the recipient and removal of that energy component will deactivate it. These methods of changing the energy or shape status of molecules can continue in a domino-effect and are how molecules communicate with one another in response to stimuli.

1.2 – How is a cell communication pathway initiated?

Stimuli for cells can be in the form of a molecule's chemical energy or a form of kinetic energy. Pain for example is kinetic energy from a force triggering a physical change in nerve cells. A chemical that acts as a stimulus triggering a response pathway is called a **ligand**. For example insulin acts as a ligand by binding to muscle and nerve cells, triggering them to absorb glucose from the blood. Both the pain & insulin signaling pathways are initiated by their stimuli but then a complex pathway begins whereby other molecules will change until the final response is achieved.

1.3 – How does a ligand's chemistry determine the pathway?

Recall the cell membrane is selectively permeable, allowing small hydrophobic substances to move directly through but hydrophilic/polar or charged substances cannot enter without a channel. Small hydrophobic ligands passing directly through the membrane usually involve pathways with minimal steps since they can reach their target in the cell without any assistance moving into the cell. Ligands such as these target **intracellular receptors** that are inside the cell. Other ligands that are hydrophilic or very large cannot directly access molecules inside the cell. These ligands target **membrane receptors** that will relay the ligand's "signal" in a long domino-effect reaction whereby molecules keep relaying signals to subsequent molecules. This pathway type is called a **signal transduction pathway**.

1.4 – How does a stimulus communicate a response over long distances?

The first type of long-distance signaling is **nerve signaling** in animals. Receptors throughout the body pick up stimuli in **sensory neurons** of eye cells, skins cells and internal organ tissue. These cells send signals via the movement of ions to the brain where **integration** connects sensory neurons to regions of the brain by **interneurons**. The signal is sent to the target area by an **efferent neuron** where a response is generated.

The second long distance pathway requires the circulatory system which transports all types of substances like oxygen, hormones and glucose. Hormones produced by various glands of the endocrine system can be stimulated by either the brain or basic feedback loops within organs. For example your fight or flight response is triggered when the brain senses a threat; nerves signal the adrenal glands to produce adrenaline that travels through the blood, stimulating increased metabolism for energy needed by the muscles. Low levels of light stimulate the brain to signal release of the hormone melatonin which travels through the blood decreasing metabolism, inducing fatigue for sleep. Both nerve & hormone signaling require many cells to communicate with each other through a series of events in each cell.

Section 2 – Intracellular Signaling mechanisms

2.1 – How does a ligand initiate a response directly?

Small hydrophobic ligands targeting intracellular receptors will first diffuse through the membrane and then directly bind to the receptor. Testosterone is a classic example in which it binds to a cytoplasm receptor forming an activated complex. The complex then diffuses into the nucleus and serves as a **transcription factor** that regulates the transcription of specific genes. These particular genes produce proteins that will inhibit the hormones LH & FSH that usually rise and fall regularly in females, regulating the female reproductive cycle. Without these hormones, female characteristics are inhibited in males while testosterone also stimulates primary male characteristics in other pathways. Most intracellular receptor ligands follow a similar trend of gene expression in the nucleus by activating transcription factors. Draw figure 11.9 on p.215 of testosterone signaling.

2.2 – What molecules are involved in signal transduction pathways?

Because signal transduction pathways involve many steps, there are many different molecules that serve as "relays" connecting the ligand's signal with a final response. Small non-protein molecules that serve as these relays are called **second messengers** and these are vital to these pathways. Second messengers include small hydrophilic molecules like calcium ions (Ca^{2+}) and **cyclic AMP** (**cAMP**).cAMP is generated from ATP by a special enzyme called adenylyl cyclase, making cAMP suited to stimulate other molecules in a pathway.

Another important class of relays is the kinases. **Kinases** are enzyme proteins that phosphorylate and thus energize other molecules in a pathway. A kinase remains active long enough to phosphorylate numerous molecules before another enzyme called a **phosphatase** deactivates the kinase by removing its phosphate. Even though just 1 ligand may initiate a pathway, kinases **amplify** the signals since they remain active for a while and activate many other kinases that activate even more kinases; therefore 1 ligand initiation can result in a response producing trillions of the same response. This process of kinases activating other kinases is called a **phosphorylation cascade**, seen on p.215.

2.3 – How do signal transduction pathways occur?

A ligand begins by binding to and activating a membrane receptor that usually is a transmembrane protein, meaning it spans from inside to outside the cell. When the ligand attaches, the active receptor triggers the activation of other molecules. **G-protein receptors** for example activate adenylyl cyclase to activate cAMP which continues the signaling via a phosphorylation cascade. **Tyrosine Kinase receptors** also become activated by ligands and involve phosphorylation cascades.

Signal transduction pathways can lead to gene regulation pathways and also many metabolic pathways in the cytoplasm. The main benefits of these pathways are the amplification stated earlier but also the many points for regulation. In a pathway with just a few steps if one molecule becomes faulty (overactive or inactive), then the response is easily disrupted. By using many relay molecules that can each be regulated, it provides the cell extra ways to regulate the overall response. If one molecule becomes faulty, another molecule in the pathway can be altered so the errors do not lead to a harmful response.

Section 3 – Regulation of Gene Expression

3.1 – How do prokaryotes regulate their gene expression?

Prokaryotes have a single chromosome with many genes but these genes are usually located in clusters called **operons**. A segment of DNA where transcription will begin is called an **operator.** If the operator is blocked by a **repressor**, gene expression will not occur. Operons that are usually off are called **inducible** because the repressor can be removed by a molecule called an **inducer**, allowing gene expression to occur. Other operons are usually on because no repressor blocks the operator, so gene expression occurs consistently. These operons are called **repressible** since a repressor can be activated by a **corepressor**, allowing the then active repressor to block the operator. Inducible operons are beneficial when a protein/enzyme needs to be made only occasionally. Repressible operons are beneficial when a protein/enzyme is made consistently but if not needed, the pathway can be shut down to conserve cell energy.

3.2 – Why do eukaryotes have more regulation of gene expression?

The trend we see among organisms is that the more complex the organism, the more complex their gene regulation. Recall that eukaryotes have multiple chromosomes each carrying many genes. It is not usually the amount of chromosomes that defines organism complexity, but rather how the expression of those chromosomes' genes is regulated. Complex organisms have a vast number of specialized cells but most contain the exact same DNA. In order to maintain order and make sure every cell is doing its job correctly and communicating with other cells correctly, eukaryote cells need many levels at which their gene expression can be regulated.

3.3 – How is DNA regulated before it is transcribed?

In the nucleus DNA is found wrapped around **histone proteins** that keep it from the grasp of transcription enzymes. **DNA methylation** assures DNA remains wrapped around the histones keeping it inactive but **histone acetylation** loosens DNA from the histones, allowing it to become available for transcription. Even when DNA becomes available for transcription it must be recognizable by RNA polymerase. Every cell has unique proteins called **transcription factors** that act as **activators** by binding to sequences of DNA called **enhancers** that bind RNA polymerase.

3.4 – How are mRNA & proteins regulated?

Recall that **alternative splicing** is when various sequences of mRNA (exons) are excised and spliced together by spliceosomes. This is also regulated by transcription factors since mRNA splicing will occur differently based on each cell's unique set of transcription factors. mRNA is also modified with a 5'-cap and a poly-A tail which make the mRNA stable as it moves towards a ribosome for translation. If the mRNA's protective ends are destroyed before reaching a ribosome, the gene will not be expressed into a protein product. Another group of molecules called **noncoding RNAs** (**ncRNA**) act to degrade mRNAs. As mRNAs are degraded and proteins not expressed, it can help determine the lifespan or activity of a cell. In terms of regulation, this is beneficial so that old cells that may be prone to DNA defects are destroyed before they cause damage. **Micro RNA** (**miRNA)** is an important example of a ncRNA that has roles in degrading mRNAs during development & in adulthood. ncRNA is thought to be coded for by about 85% of our entire genome, with 15% coding for actual proteins. This discovery shows just how significant ncRNA is to eukaryote's normal development & growth.

After mRNA is translated into proteins, these proteins also have limited lifespans helping to regulate cell health like in the example with ncRNA. However, special enzymes called **proteasomes** degrade proteins in cells.

Section 4 –Mutations Causing Faulty Pathways

4.1 – What types of mutations result from faulty DNA Proteins?

If DNA replication proteins are not regulated properly, mutations in DNA can result and subsequently be passed on to newly divided cells. When these errors are passed to gametes, they become heritable mutations. Insertions or deletions of base pairs can interrupt the codon reading frame of a gene, called a **frameshift mutation**. Substitutions can mistakenly add one base in place of another. For example UUU codes for phenylalanine but if in a **missense mutation** it changes to UUA, this codes for Leucine, a different amino acid. Other instances cause a normal codon being substituted for a stop codon which can prematurely terminate the protein, called a **nonsense mutation**. Finally some mutations cause a base to change but it still codes for the same amino acid, called a **silent mutation** which has no effect on the protein. These DNA mutations have varied effects on a phenotype, all subject to providing variation for natural selection to act upon.

4.2 – How does a faulty gene lead to Down-regulated disorders?

Any condition in which a substance causes a decrease or shut-down in a process is called **down-regulation**. While many processes rely on being able to downregulate a process, a mutation in the down-regulator molecules can be harmful. For example the cell cycle regulator molecule cyclin needs to fluctuate correctly to assure cells divide at specific times only. Cancer can result when a faulty gene is expressed that doesn't allow the shut-down of the cyclin gene expression pathway. The cyclin gene constantly gets expressed because the down-regulator doesn't function. This is also linked to why apoptosis (programmed cell death) doesn't happen in cancer cell. Metabolic disorders can simply be a faulty gene doesn't code for a protein like insulin. Diabetic people cannot regulate blood sugar because their insulin gene or insulin receptor gene has mutated to no longer code for the correct product.

4.3 – How does a faulty gene lead to up-regulated disorders?

When a process can be amplified or turned on it is considered **up-regulated**. Growth factors regulating cell division during embryo development are coded by the Hedgehog genes. Usually these genes up-regulate cell divisions by coding for DNA transcription factors necessary for the cell's growth & division. As adults, these hedgehog genes are silenced by other regulator proteins. In many cases of cancer, the Hedgehog genes have mutated and become unresponsive to controls, thus causing uncontrolled cell division (cancer). One reason for this is that the mutation caused amino acids essential for regulator binding to no longer exist.

Section 5 – Sources of Mutations

5.1 – How do prokaryote genes mutate?

Prokaryotes don't undergo sexual reproduction so their main source of mutations is by natural errors in DNA replication. Because they reproduce so quickly, mutations arise seemingly fast compared to slowly reproducing organisms like animals. Prokaryotes also exchange DNA with each other during **conjugation** via through projections from their cytoplasm called pili. Pili form temporary exchange bridges where plasmids can be transferred between different cells, also contributing to their rapid mutation. **Transformations** also occur naturally where fragments of DNA are taken up from the environment. All of these processes lead to changes in prokaryote genomes over time, leading to evolution.

5.2 – How do eukaryote genes mutate?

Sexual reproduction includes **crossing over** during meiosis. Sometimes beneficial combinations result in beneficial phenotypes but other times faulty combinations arise leading to miscarriages or genetic defects & disorders. **Transposons** are parts of DNA that, for some undiscovered reason, excise and relocate to other regions of DNA. Many chemicals cause mutations which have been linked to cancers and are called **carcinogens**. Other mutation-inducing chemicals causing other changes besides cancers are called **mutagens**. Both agents have the ability to mutate DNA by breaking it, deforming it or disrupting replication. They can also act as binding agents that block certain enzymes important to life function. Carcinogens & mutagens can occur naturally in cells or the environment but also come from man-made substances like ethidium bromide & BPA. Prokaryote cells are also affected by mutagens & carcinogens, increasing their evolution even more so.

5.3 – How do viruses contribute to mutations?

Viruses are pseudo-organisms made of an outer covering called a capsid covering an internal core of DNA or RNA. When viruses infect living cells, they sometimes embed their nucleic acid into the host's DNA, called the **lysogenic cycle**. For DNA viruses this happens in a few quick steps but RNA viruses, called **retroviruses**, must perform an additional step. They use the host's molecules to express an enzyme called **reverse transcriptase** which turns their viral RNA into viral DNA which can then embed into the host's DNA. Each cell division we undergo with a virus inside will produce all cells also with the viral DNA. Many viruses quickly detach their nucleic acids for incorporation into new capsids, and then they break open the cells & target more for the same fate.

Many retroviruses are menacing because they do not detach their DNA from ours ever; it is with us forever and is why some viruses like HPV & herpes are currently impossible to remove. As viruses embed their DNA into ours, it may interrupt a normal gene sequence leading to disorders. HPV and herpes are thought to cause warts & some cancers because the normal gene sequences of infected cells become altered when viral DNA inserts itself, leading to upregulation of cell cycle regulators.

When parts of a host DNA detaches when the viral nucleic acid detaches, it can be introduced into a new host. This transfer of DNA from one host into the genome of a different host is called **transduction**. Each time you are infected by a virus you have the potential to gain some DNA from other bacteria, people, or any other living thing and in turn some of your DNA could be transferred to other organisms.

Section 6 –Nerve Signaling Pathways

6.1 – How does the structure of a neuron suit its function?

A nerve cell (neuron) has a **cell body** with branching **dendrites** that receive stimuli from the environment or other cells. Opposite the dendrites' receiving ends is a long branch called an **axon** that transmits signals along its length until branching into **synaptic terminals**. Synaptic terminals contain vesicles filled with neurotransmitter molecules that are released when the axon's signal reaches them. The first neuron's synaptic terminals lie close to receiving cells but a gap called the **synapse** is where neurotransmitters diffuse across to the next receiving cell. The long axon allows for a signal to be transmitted very long distances and branched dendrites allow for collecting stimuli at many points along the cell body. Surrounding most neurons is also a layer of insulating protein called **myelin sheaths** that improve the conduction speed of neuron signaling. Draw the basic neuron features in figure 48.4 on p.1047.

6.2 – Why is a neuron suited to transmit electrical impulses?

A neuron can be found in a **resting state** or an **action potential** state. At rest, the **sodium potassium pump** pumps out 3 Na+ and pumps in 2 K+, making the inside overall less positively charged than the outside of the neuron. In addition, **ion channels** selective for K+ remain open, allowing the K+ pumped in to rush back out down its concentration gradient. Overall the charge inside of a neuron at rest is **-70mV**. There are other ion channels as well that only open and close when a charge difference is applied, called **voltage-gated channels**. The neuron is a cell loaded with sodium potassium pumps & ion channels which suit its ability to reverse the charge along the axon very quickly. This charge reversal using the flow of ions in or out of the cell is the basis of an electrical impulse, called an **action potential**.

6.3 – How is an action potential generated & conducted?

When a stimulus is applied, some gated Na+ channels open allowing some Na+ to enter the cell down its concentration gradient. This causes the inside to start reversing its charge to positive, called **depolarization**. After a certain voltage called the **threshold**, the action potential increases as many more Na+ channels open and further depolarize the neuron causing it to become positive. As the ions begin to diffuse back out of the cell through open channels, the voltage gated channels begin to close and the sodium potassium pump restores the resting state. The open K+ channels actually cause **hyperpolarization** when the neuron becomes momentarily more negative than usual.

Depolarizations in a region have enough charge to cause depolarizations in nearby regions of the axon. Hyperpolarization assures that the region just having gone through an action potential cannot have an action potential travel "backwards" because it is too negative to become depolarized again for a small period of time called the **refractory period**. In this way, action potentials can only be conducted along the axon ahead of the action potential, moving towards the synaptic terminals.

6.4 – How do neurotransmitters function?

When an action potential reaches the synaptic terminals, it causes calcium channels to open. Calcium binds to the vesicles containing neurotransmitters causing them to fuse with the membrane and be released into the synapse. **Neurotransmitters** diffuse across the synapse where they bind with a receptor on the next cell. If the next cell is another neuron nerve signaling will continue until a target tissue is reached. When the target tissue is reached, the response can be anything from a motor response, a metabolic response or a gene expression response.

Some useful diagrams are shown on pp.1052 -1055 for reference as needed.

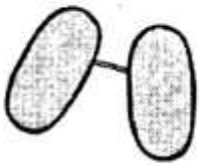
1.

A dog is following the scent of a jackrabbit. Which of the following accurately describes how the dog's brain integrates information for smell?

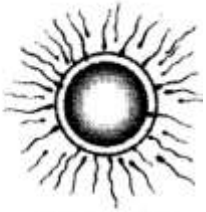
(A) Chemoreceptors in the brain send impulses for smell in the nasal cavity.
(B) Chemoreceptor cells in the nasal cavity send impulses to the appropriate area of the brain.
(C) Chemoreceptors on epithelial cells of the tongue send hormones to the appropriate area of the brain.
(D) Receptors originating in the nose send action potentials to the motor regions of the brain.

2.

Crossing Over



Conjugation



Fertilization

5. The processes illustrated in the models depicted above all result in which of the following?

(A) Transcription
(B) An increase in genetic variation
(C) An increase in the chromosome number
(D) Horizontal gene transfer

3.

A new mutation that arose in one copy of gene *X* in a somatic cell resulted in the formation of a tumor. Which of the following pieces of evidence best describes how the new mutation directly caused the tumor?

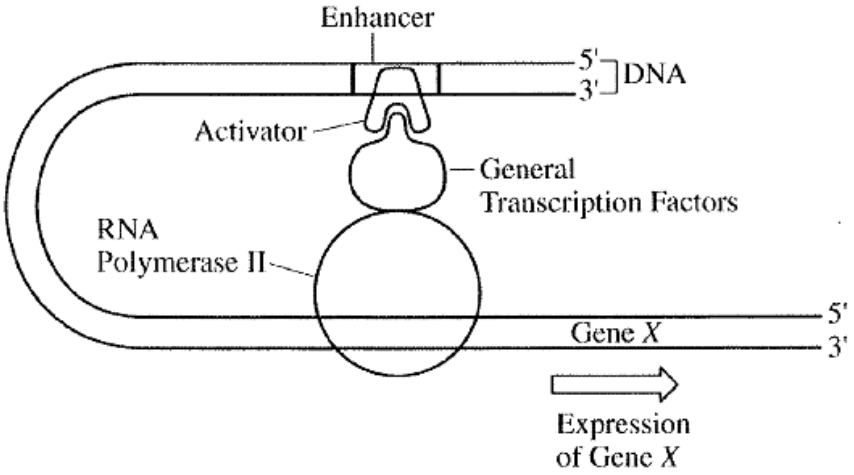
(A) Protein X normally stimulates cell division, and the mutation created an overactive version of protein X.
(B) Protein X normally activates a growth hormone receptor, and the mutation decreased the stability of protein X.
(C) Protein X normally prevents passage through the cell cycle, and the mutation created an overactive version of protein X.
(D) Protein X normally regulates gene expression, and the mutation created an underactive version of protein X that blocked the cell cycle.

4.

Cell communication is critical for the function of both unicellular and multicellular eukaryotes. Which of the following is likely true of cell signaling?

(A) Cell signaling uses the highest molecular weight molecules found in living cells.
(B) Cell signaling has largely been replaced by other cell functions in higher mammals.
(C) Similar cell signaling pathways in diverse eukaryotes are evidence of conserved evolutionary processes.
(D) Cell signaling functions mainly during early developmental stages.

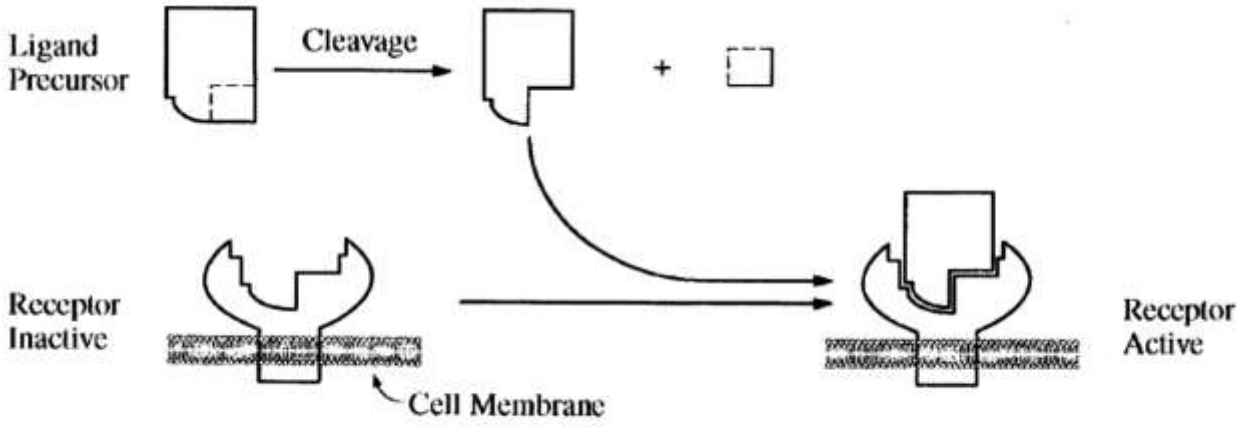
5.



The figure above depicts the DNA-protein complex that is assembled at the transcriptional start site of gene *X* when the expression of gene *X* is activated in liver cells. Previous studies have shown that gene *X* is never expressed in nerve cells. Based on the diagram, which of the following most likely contributes to the specific expression pattern of gene *X* ?

(A) Expression of gene *X* produces large amounts of tRNA but undetectable amounts of mRNA.
(B) The general transcription factors inhibit the activation of gene *X* in liver cells by blocking the activator from binding to RNA polymerase II.
(C) The activator is a sequence-specific DNA-binding protein that is present in some tissues but not in other tissues.
(D) The enhancer is a unique DNA segment that is added to the nuclear DNA of some cells of an organism during the process of mitotic cell division but not other cells.

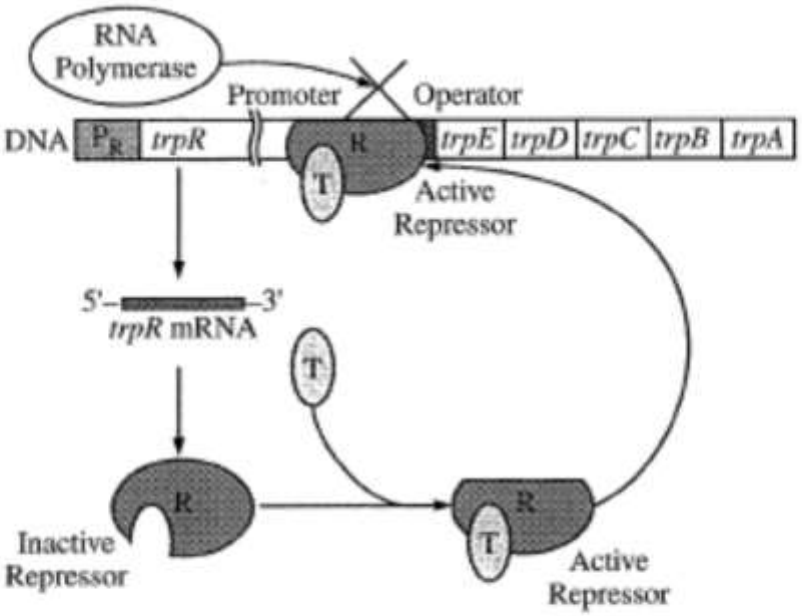
6.



The figure above shows a model of a ligand precursor being cleaved to produce an active ligand that binds to a specific receptor. Which of the following is most likely to reduce the binding of the active ligand to its receptor?

(A) A change in the cytoskeletal attachment of transmembrane proteins
(B) The presence of a large amount of the precursor form of the ligand
(C) An increase in the ratio of the number of unsaturated to the number of saturated fatty acid tails of the membrane lipids
(D) A mutation in the receptor gene that causes a substitution of a charged amino acid for a nonpolar amino acid in the ligand binding site of the receptor

7.



R	= Repressor molecule
T	= Tryptophan molecule
P_R	= Promoter for the *trpR* gene
trpR	= Repressor gene
Operator	= Binding site for repressor molecule

The *Trp* operon is a coordinately regulated group of genes (*trpA–trpE*) that are required for tryptophan biosynthesis in *E. coli*. Based on the figure above, which of the following correctly describes the regulation of the *Trp* operon?

(A) In the absence of tryptophan, the repressor is active and binds to the *Trp* operator, preventing RNA polymerase from transcribing the operon.
(B) In the presence of tryptophan, the repressor is active and binds to the *Trp* operator, preventing RNA polymerase from transcribing the operon.
(C) In the absence of tryptophan, the *trpR* gene is inactive, preventing the production of the repressor that blocks expression of the operon.
(D) In the presence of tryptophan, the *trpR* gene is inactive, preventing the production of the repressor that blocks expression of the operon.

8.

When a stimulus is applied to a receptor in the skin, an action potential is propagated along a neuron to the brain, where another signal is sent back to the muscle for a response.

Which of the following best describes what occurs when the action potential reaches a chemical synapse at the end of an axon?

(A) The action potential jumps from one axon to the next connecting axon.
(B) The action potential travels through the synapse to the next connecting dendrite.
(C) The action potential jumps the synapse to the next connecting dendrite.
(D) The action potential causes a release of neurotransmitters that travel across the synapse.

11.

Methicillin-resistant *Staphylococcus aureus* (MRSA) can be a serious threat to human health. There is evidence that *S. aureus* infections are common in hospitals and that MRSA have become resistant to other antibiotics besides methicillin. This suggests that the rapid evolution of resistance in the bacteria poses a serious public-health challenge. Which of the following best explains the ability of MRSA to evade existing drug therapies?

(A) MRSA have very long generation times and very large population sizes.
(B) MRSA develop new alleles by intentionally introducing specific mutations that will give them a selective advantage over other bacteria.
(C) MRSA metabolize many drugs in their lysosomes and therefore evolve resistance at a high rate.
(D) MRSA exchange genetic material with other antibiotic-resistant bacteria, which can spread resistance in the *S. aureus* population.

9. The table below describes the action of two genes involved in the regulation of nervous system development in the nematode *C. elegans*.

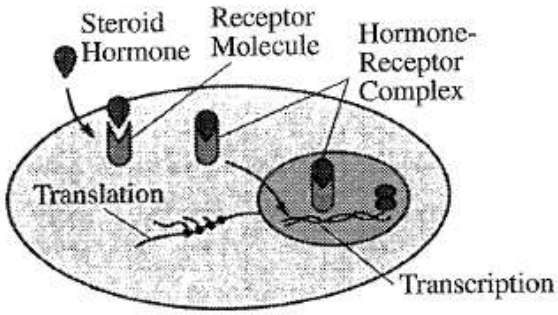
	Gene *A*	Gene *B*	Observation
Pattern 1	Inactive	Inactive	No neurons develop.
Pattern 2	Inactive	Active	No neurons develop.
Pattern 3	Active	Inactive	Greater-than-normal number of neurons develop.
Pattern 4	Active	Active	Normal number of neurons develop.

Which of the following claims is best supported by the data?

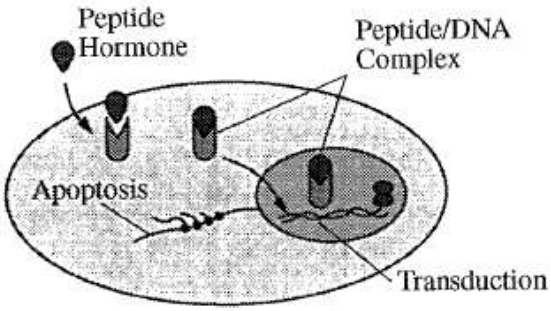
(A) Gene *A* promotes neuron development; gene *B* promotes programmed cell death in neuronal precursors.
(B) Gene *A* promotes programmed cell death in neuronal precursors; gene *B* promotes neuron development.
(C) Gene *B* must be active before gene *A* can function.
(D) Gene *B* must be inactive before gene *A* can function.

12. Which of the following diagrams best represents hormone-activated gene expression?

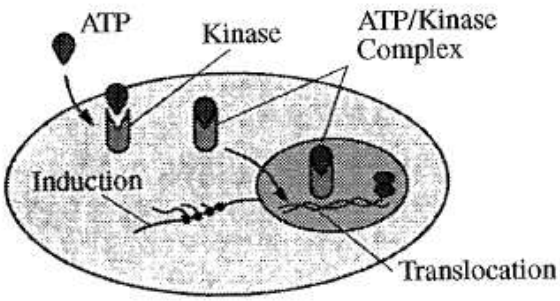
(A)



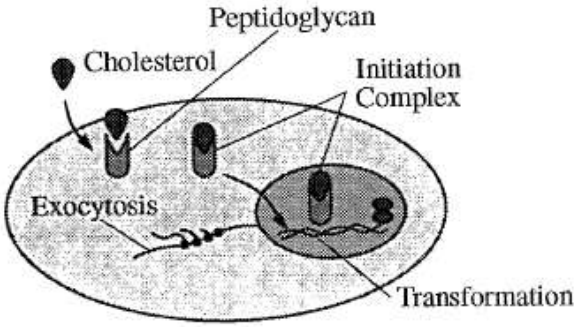
(B)



(C)



(D)



13. The bacterium *Vibrio cholerae* is harmless unless a lysogenic bacteriophage provides the gene coding for the cholera toxin, which converts the bacterium to the virulent form that causes cholera. Which of the following best explains how the gene encoding cholera toxin becomes part of the bacterial genome?

(A) The bacteriophage inserts the toxin gene into the host cell DNA, and the gene is expressed with the rest of the host cell's genes.

(B) The bacteriophage makes copies of the toxin gene and expresses the copies inside the bacteriophage.

(C) The bacteriophage converts its toxin gene into mRNA, which is then translated by the host cell.

(D) The bacteriophage transforms itself into a self-replicating protein that can survive inside the host cell.

The three-spined stickleback (*Gasterosteus aculeatus*) is a small fish found in both marine and freshwater environments. Marine stickleback populations consist mostly of individuals with pronounced pelvic spines, as shown in Figure 1. Individuals in freshwater stickleback populations, on the other hand, typically have reduced pelvic spines, as shown in Figure 2.

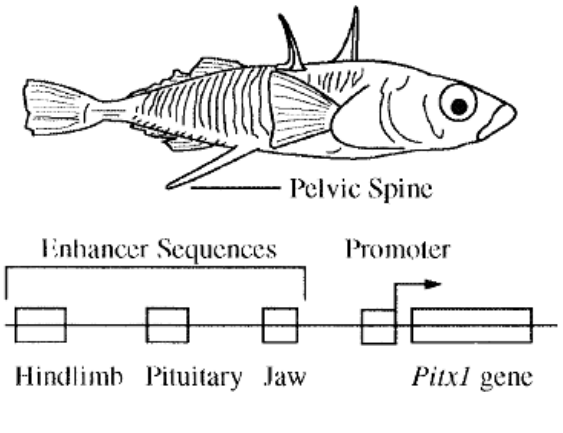


Figure 1. Marine stickleback

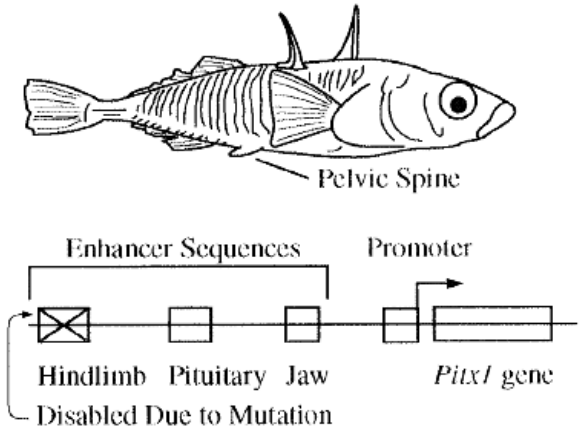


Figure 2. Freshwater stickleback

As represented in Figure 1 and Figure 2, the phenotypic difference between marine and freshwater sticklebacks involves *Pitx1*, a gene that influences the formation of the jaw, pituitary gland, and pelvic spine. Enhancer sequences upstream of the *Pitx1* genetic locus regulate expression of the *Pitx1* gene at the appropriate times and in the appropriate tissues during development. Previous studies have found that a mutation in the hindlimb enhancer interferes with the formation of a pronounced pelvic spine.

14. Which of the following best describes how sticklebacks in the same population with identical copies of the *Pitx1* gene can still show phenotypic variation in the pelvic spine character?

(A) The *Pitx1* gene is carried on different chromosomes in different individuals.
(B) Expression of the *Pitx1* gene is affected by mutations at other genetic loci.
(C) The genetic code of the *Pitx1* gene is translated differently in males and females.
(D) The subcellular location of the *Pitx1* gene changes when individuals move to a new environment.

15. A mutation that affects *Pitx1* gene function in all tissue types is most likely to be at which of the following genetic loci?

(A) Hindlimb enhancer
(B) Pituitary enhancer
(C) Jaw enhancer
(D) Promoter

16. In sticklebacks, which of the following is most likely to occur if the jaw enhancer is disabled instead of the hindlimb enhancer?

(A) The jaw and a pronounced pelvic spine develop normally because the *Pitx1* gene is expressed in both developing tissues.
(B) Neither the jaw nor a pronounced pelvic spine develop normally because there is no *Pitx1* gene expression in either developing tissue.
(C) The jaw develops normally, but a pronounced pelvic spine does not develop because the *Pitx1* gene is expressed in the developing jaw but not in the developing pelvis.
(D) The jaw does not develop normally, but a pronounced pelvic spine does develop because the *Pitx1* gene is expressed in the developing pelvis but not in the developing jaw.

Refer to the information below to answer questions 17 & 18 on the following page.

Ascorbic acid (vitamin C) is an organic molecule necessary for the health of plants and animals. The majority of animals, including most mammals, synthesize ascorbic acid from organic precursors, but some primates are unable to synthesize ascorbic acid and must instead acquire it from dietary sources, such as certain fruits and vegetables.

The *L-gulonolactone oxidase (GULO)* gene encodes an enzyme that catalyzes a required step in the biosynthesis of ascorbic acid. Most mammals carry a functional copy of the *GULO* gene, but some primates carry only a *GULO* pseudogene, which is a nonfunctional variant.

A comparison of *GULO* genes and *GULO* pseudogenes from different animals can provide insight into the evolutionary relatedness of the animals. In Table I, selected members of some mammalian groups are listed, along with an indication of their ability to synthesize ascorbic acid. Table II shows an alignment of amino acid coding sequences from homologous regions of the *GULO* genes and *GULO* pseudogenes of the organisms listed in Table I. Figure 1 represents the universal genetic code.

TABLE I: SELECTED MAMMALIAN GROUPS

Group	**Selected Members**	**Biosynthesis of Ascorbic Acid**
Nonprimate mammals	Elephant, mouse	Yes
Primate mammals	Lemur	Yes
	Orangutan, chimpanzee	No
	Human	No

TABLE II: DNA SEQUENCE ALIGNMENT*

	Relative Positions of Nucleotides in Nontemplate (Coding) Sequence																										
	1 (5′)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27 (3′)
Elephant	G	A	C	A	C	C	C	A	T	C	T	G	A	A	G	A	A	G	T	C	G	G	A	A	T	A	C
Mouse	G	A	C	A	G	C	C	A	C	C	T	G	A	A	G	A	A	G	T	C	T	G	A	G	T	A	C
Lemur	G	A	C	A	G	C	C	A	C	C	T	G	A	A	G	A	G	G	T	C	C	G	A	G	T	A	C
Orangutan	G	A	C	A	G	C	-	A	T	T	G	G	A	A	G	A	A	A	T	C	T	G	A	G	G	A	C
Chimp	G	A	C	A	G	C	-	A	T	T	G	G	A	A	G	A	A	A	T	C	T	G	A	G	G	A	C
Human	G	A	C	A	G	C	-	A	T	T	G	G	A	A	G	A	A	A	T	C	T	G	A	G	G	A	C

*For each DNA segment, the alternating shaded and unshaded nucleotides indicate the triplet codons of the open reading frame, shown from left (5′) to right (3′) as the nontemplate (coding) strand. An "–" indicates the absence of a nucleotide.

17.

Comparison of DNA sequences in Table II suggests that a functional *GULO* gene in lemurs can have a G, C, or T at position 21 but only a G at position 22. Which of the following pairs of predictions is most helpful in explaining the discrepancy?

	A substitution at position 21 would result in	**A substitution at position 22 would result in**
(A)	No change to the protein	A premature stop codon or an amino acid with different biochemical characteristics
(B)	A different amino acid	A premature stop codon or an amino acid with different biochemical characteristics
(C)	No change to the protein	A frame shift producing an inactive protein
(D)	An amino acid with different biochemical characteristics	No transcription of the gene

18.

Which of the following is the most likely effect of the mutation at nucleotide position 7 in the *GULO* gene of humans?

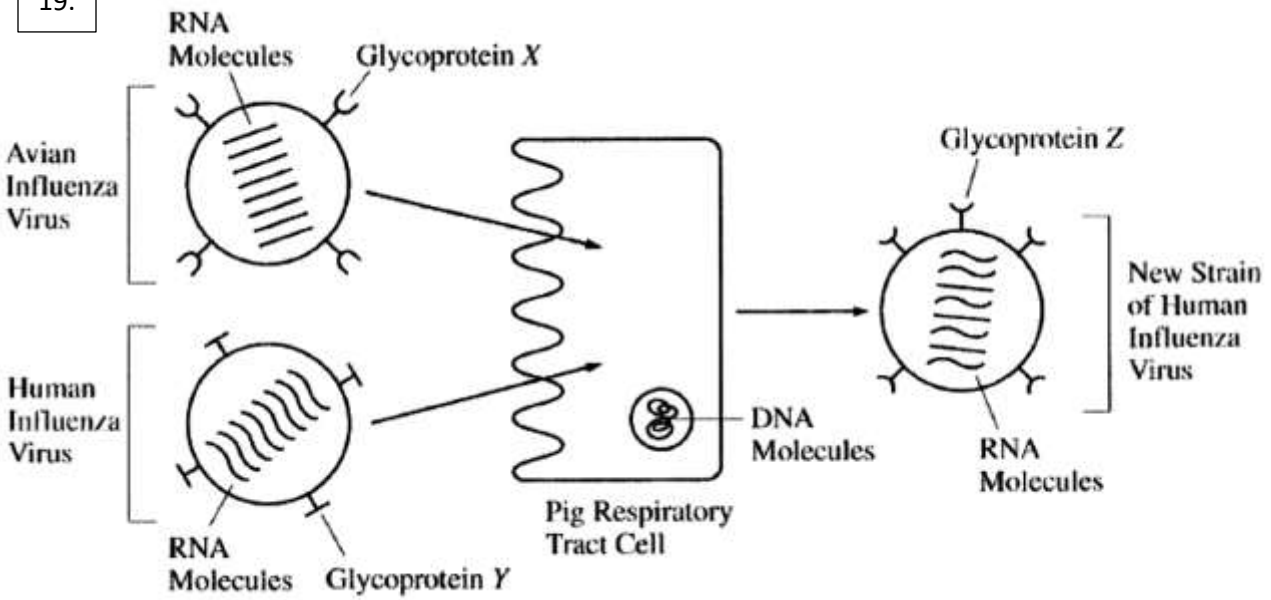
(A) The mutation results in the deletion of the *GULO* gene, so no polypeptide can be translated.

(B) The deletion of the single nucleotide causes a frame shift, changing the primary structure downstream of the mutation and resulting in a nonfunctional protein.

(C) The point mutation causes a substitution of the amino acid isoleucine (Ile) for histidine (His) at position 7, resulting in a protein with higher than normal activity.

(D) The substitution of a single nucleotide in the *GULO* coding region results in a stop codon. This results in a smaller nonfunctional protein.

19.



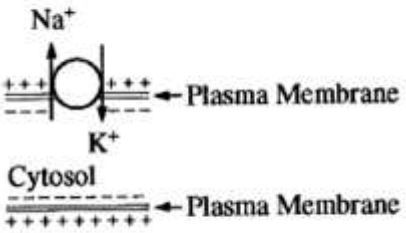
The cells lining the respiratory tract of pigs have receptors for both avian and human influenza viruses. Based on the model above, which of the following best describes the origin of the new strain of human influenza virus?

(A) The new viral strain inherited a mixture of genetic material from both avian influenza virus and human influenza virus.
(B) The new viral strain inherited RNA molecules from the avian influenza virus and packaged them inside the human influenza virus membrane.
(C) The new viral strain inherited a mutant DNA molecule from the pig respiratory tract cell.
(D) The new viral strain inherited an RNA molecule that had recombined with a DNA molecule from the pig respiratory tract cell.

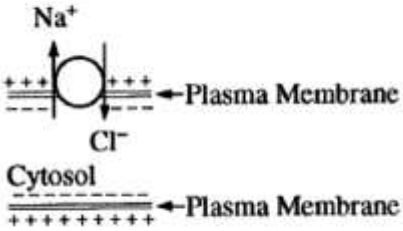
20.

Which of the following representations best shows a portion of an axon at rest (before or after an action potential)?

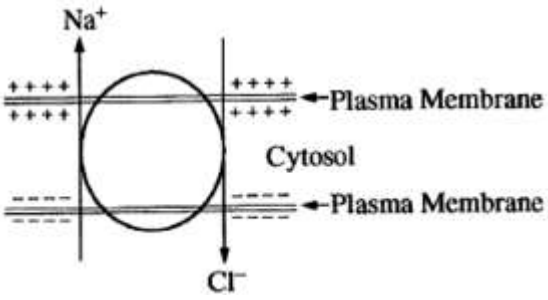
(A)



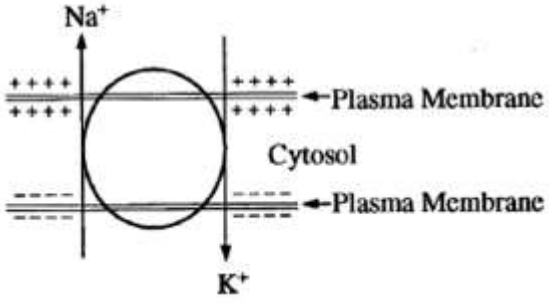
(B)



(C)



(D)



Use the information below to answer questions 21-23 on the following page.

Insulin, a hormone secreted by pancreatic cells, stimulates glucose uptake in skeletal muscle cells by mobilizing glucose transporter proteins (GLUT4) to the plasma membrane. As depicted in Figure 1, binding of insulin to the insulin receptor triggers an intracellular signaling cascade in which certain molecules activate other molecules in a relay of the hormone signal to cell targets. One outcome of the signaling cascade is mobilization of GLUT4 from vesicle storage sites in the cytoplasm to sites at the cell surface, where GLUT4 allows glucose to enter the cell.

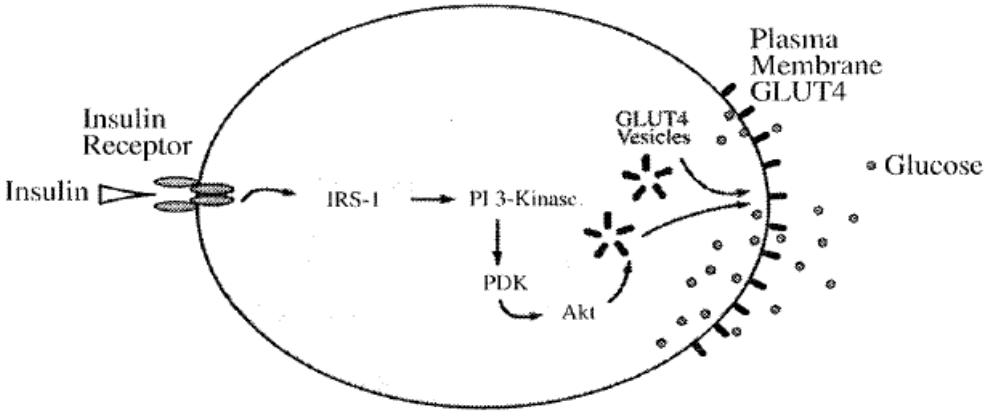


Figure 1. Insulin signaling in muscle cells

In type 2 diabetes, the cellular response to insulin is disrupted, and individuals with type 2 diabetes cannot properly regulate their blood glucose levels. In an investigation of the insulin signaling pathway, samples of skeletal muscle were isolated from individuals who have type 2 diabetes and from individuals who do not. The results of several experiments that were performed on the muscle samples are shown in Figure 2, Figure 3, and Figure 4.

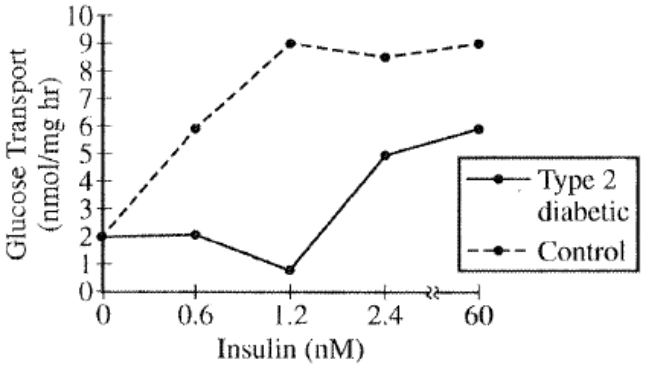


Figure 2. Insulin-stimulated glucose uptake

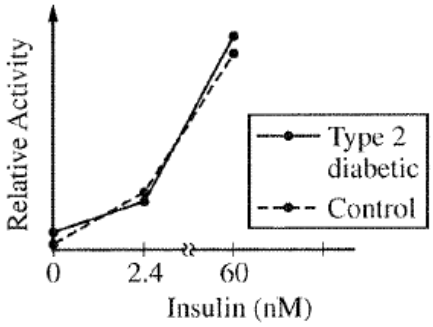


Figure 3. Insulin receptor activation

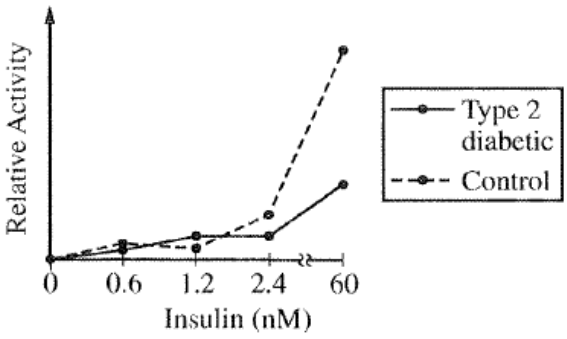


Figure 4. IRS-1 activation

21. Which of the following is a valid interpretation of the experimental results that explains how individuals with type 2 diabetes differ from individuals without diabetes?

(A) The relatively low levels of glucose uptake in individuals with type 2 diabetes indicate that mobilization of GLUT4 to the cell surface is reduced in muscle cells of those individuals.
(B) The relatively low levels of glucose uptake in individuals with type 2 diabetes indicate that no functional GLUT4 protein is produced in the muscle cells of those individuals.
(C) The absence of activated insulin receptors in individuals with type 2 diabetes indicates that no insulin is secreted by the pancreatic cells of those individuals.
(D) The absence of activated IRS-1 in individuals with type 2 diabetes indicates that no functional insulin receptor protein is produced in the muscle cells of those individuals.

22. Based on the experimental results, which of the following describes the most likely defect in muscle cells of patients with type 2 diabetes?

(A) Insulin receptor proteins do not reach the cell surface.
(B) Insulin does not activate its receptor.
(C) IRS-1 activation is reduced at high insulin concentrations.
(D) GLUT4 blocks glucose from entering cells.

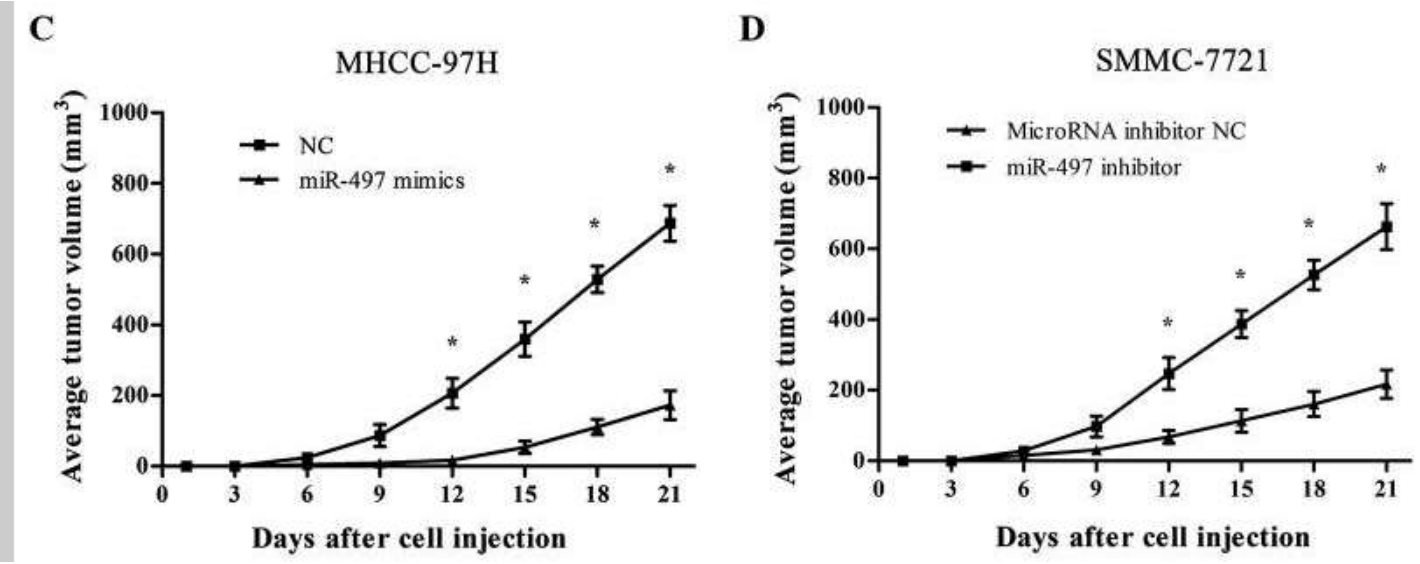
23. Based on the information presented, which of the following genetic changes in an individual without diabetes is most likely to result in a disrupted cellular response to insulin signaling similar to that of an individual with type 2 diabetes?

(A) A deletion in the gene encoding the insulin receptor that removes only the cytoplasmic domain of the protein
(B) Duplication of the gene encoding a PI-3 kinase that results in synthesis of a muscle-specific variant of the enzyme in skin cells as well as in muscle cells
(C) A mutation in the gene encoding IRS-1 that causes the protein to be active in muscle cells even in the absence of insulin signaling
(D) Insertion of a small segment of DNA into the promoter of the *Glut4* gene that results in increased synthesis of GLUT4 proteins in muscle cells

Calculation Question

The figures below show 2 cancerous tissues samples under different treatments. Figure C shows tissues treated with miRNA mimics and a control group, NC (no mimics). Figure D shows tissues treated with miRNA inhibitors and a control group, NC (No inhibitors). The * signifies that the data were statistically significant.

Source: *MicroRNA-497 regulates cell proliferation in hepatocellular carcinoma*, Oncology Letters, 2016.



For the 18 days after injection timeframe, calculate **how many times more effective** the experimental treatment was compared to its control group, for the tissue sample that had the most success at decreasing tumor volume. Show all your work and express your answer as a whole number.

1.

Loeys-Dietz syndrome (type 2B) is a human genetic disorder associated with mutations in the *LDS2B* gene. Researchers have proposed that the *LDS2B* gene produces a growth factor receptor protein that regulates cell signaling pathways. The predicted product of the gene is a 565-amino acid protein with structural regions that bind to signaling molecules, span the plasma membrane, and have protein kinase activity. Protein kinases are cellular enzymes that transfer phosphate groups from ATP to target proteins. A representation of the *LDS2B* gene is shown in Figure 1.

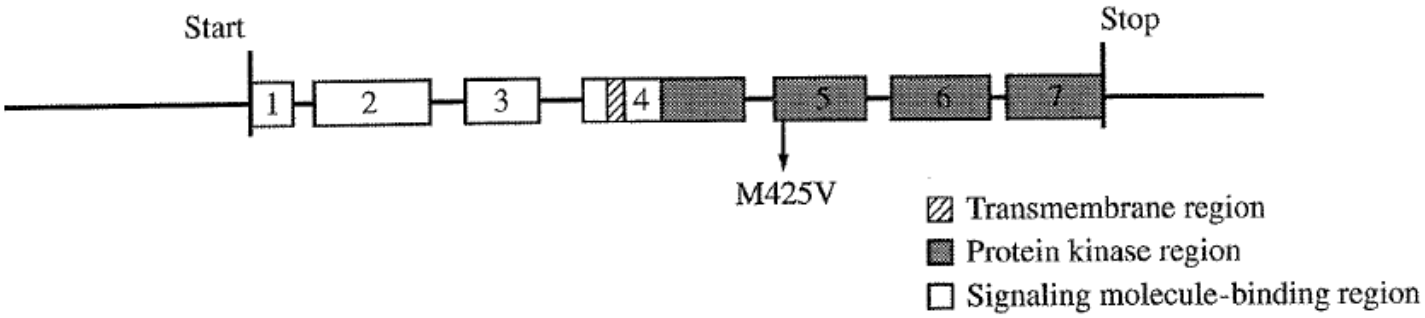


Figure 1. Genomic structure of the *LDS2B* gene. The seven exons (numbered rectangular boxes), the introns (thin lines between the boxes), and the start and stop signals for translation are represented. The portions of the gene that encode the different structural regions of the protein are shown, and the location of a methionine-to-valine substitution at position 425 of the encoded polypeptide (M425V) is indicated.

(a) One genetic change associated with the disorder results in a methionine-to-valine substitution at amino acid position 425 of the encoded polypeptide, as shown in Figure 1. Using the codon table in Figure 2, **predict** a DNA point mutation that will result in a methionine-to-valine substitution.

(b) **Propose** THREE features of a model to connect the genetic mutation you predicted with the activity of a signaling pathway involving the *LDS2B* gene product.

2.

Tetrodotoxin (TTX) is a neurotoxin that blocks the Na^+ channels of the neuronal membrane. The puffer fish, which contains TTX in its liver, is considered a delicacy in Japan even though eating incorrectly prepared puffer fish can be fatal to humans.

(a) **Describe** TWO functions of neurotransmitters at the postsynaptic membrane.

(b) Based on the information provided above, **explain** how TTX most likely interferes with the transmission of information across synapses.

3. For each of the following processes describe the steps of initiation, transfer and reception of the information.

(a) A signal transduction pathway (b) Nerve cell signaling pathway

4. Contrast the mechanisms of gene regulation among eukaryotes & prokaryotes.

5. Describe 3 mechanisms by which organism genomes can change within their lifetime.